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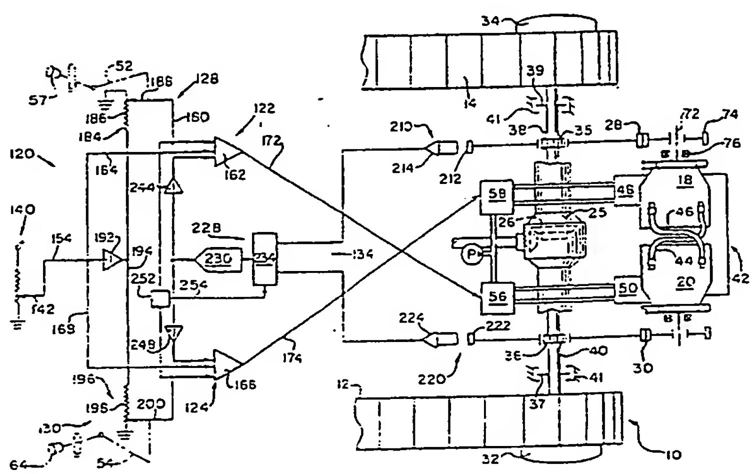
(54) Speed sensor synchronized, hydromechanical steering differential

(57) A crawler tractor (10) adapted for stepless hydromechanical steering by driving. The power train terminates in a novel hydromechanical steering differential (25) delivering its output to an oppositely extending pair of axles (38, 40) at the sides of the tractor, which differential is selectively forced into differentialing by a variable displacement crossfeeding pair of axle-interconnecting hydrostatic pump/motor units (18, 20) which, in a primary turning mode thereof, selectively drives either axle at only some hydrostatically fixed *reduction* drive ratio to the other and, secondarily whenever necessary, which differential speed sensor mechanism (134) causing a synchronized mode of the axle-interconnecting hydrostatic pump/motor units so that both axles turn at stricly a *1:1* hydrostatically fixed drive ratio therebetween.



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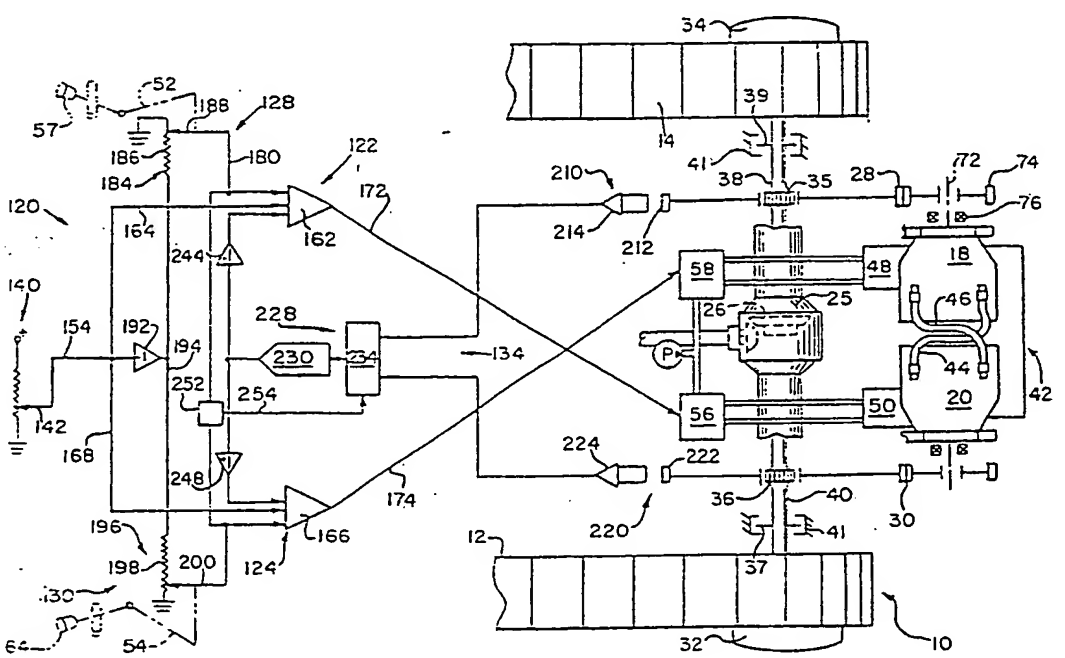

(57) Abstract

A crawler tractor (10) adapted for stepless hydromechanical steering by driving. The power train terminates in a novel hydromechanical steering differential (25) delivering its output to an oppositely extending pair of axles (38, 40) at the sides of the tractor, which differential is selectively forced into differentialing by a variable displacement crossfeeding pair of axle-interconnecting hydrostatic pump/motor units (18, 20) which, in a primary turning mode thereof, selectively drives either axle at only some hydrostatically fixed *reduction* drive ratio to the other and, secondarily whenever necssary, which differential speed sensor mechanism (134) causing a synchronized mode of the axle-interconnecting hydrostatic pump/motor units so that both axles turn at strictly a *1:1* hydrostatically fixed drive ratio therebetween.

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SPEED SENSOR SYNCHRONIZED, HYDROMECHANICAL STEERING DIFFERENTIAL

SPECIFICATION

This case is a continuation in part to our Kolthoff, Jr., copending application U.S. Serial No. _______ and owned by the same assignee.

It similarly relates to the power train adapting a crawler tractor for stepless hydromechanical or electromechanical steering by driving. But the similarity ceases by the oversimplification we herein achieve after providing that the power train terminate in a novel hydromechanical or electromechanical steering differential delivering its output to an oppositely extending pair of final drive axles at the respective traction driven sides of the tractor. Distinctively so, the steering differential we provide herein is selectively forced into differentialling by a variable displacement cross-feeding pair of axle-interconnecting hydrostatic pump/motor units or motor/generator units which, in a primary turning mode thereof, selectively drives either axle at only some hydrostatically or electrically fixed reduction drive ratio to the other up to and including a reduction in the slower axle to zero speed for pivot turn and, secondarily whenever necessary, automatically forced into a straight line steering by differential speed sensor mechanism causing a synchronized mode of the axle-interconnecting hydrostatic or electrical units so that both axles turn at strictly a <u>1:1</u> hydrostatically or electrically fixed drive ratio therebetween. The difference we have come to recognize between the two is that the primary mode constantly takes operator adjustment and operator judgment which cannot be left to automatic machinery, whereas the secondary mode lends itself to our rendering it fully automatic.

This same oversimplification achieved by our invention becomes evident by inspection when certain prior disclosures are considered among the background patents,

especially expired patent no. 2,336,911. The relevance of the patent will be noted with respect to the opposite track axles it discloses, having separate interconnections thereto connected in parallel power paths as provided first, mechanically by an interconnecting differential, and as provided second, hydraulically by a 3-unit interconnecting hydrostatic bi-directional drive; the patented 3-unit arrangement requires an external source of power absent from the present self-powered invention.

Further background patents of relevance include but are not limited to U.S. Nos. 2,996,135, 2,394,119, 2,996,135, 3,744,584, 3,815,698, 3,862,668, 4,019,596, 4,093,048, and particularly Nos. 2,336,912, 2,353,554, 2,401,628, 2,446,242, 2,580,946, and 3,914,938.

In general, a crawler tractor has straight line steering or else it turns, the same as just mentioned and depending in all cases upon whether, relative to a reference track driven by the axle at one side, the same speed or a slower speed is being attained by the other (inside) axle drive track. According to the present invention, the novel steering differential drive in which the power train terminates as just alluded to affords a shaft-driven differential system which when so driven is self-powered for effecting turns and self-powered for the necessary differentialling corrections to effect straight line steering; in this aspect thereof, our invention offers full time hydrostatic power steering.

The objectives, if not seen as altogether unexpected here, are nevertheless not believed all obvious ones and include: utilizing dual variable displacement pump/motor units as the crossfeeding hydrostatic units added to a steering differential in parallel therewith in a self-powered manner adapting it for stepless hydrostatic/mechanical steering; doing so in that manner using small size units for each of the dual units, by reason of the fact that the differential applies the total output whereas at most only a portion of total output is ever utilized by the

hydrostatic unit in hydraulically superimposing that differential in speed which is needed between the two axles; providing a novel controlled slip differential wherein the runaway axle is not frictionally dragged down in speed, but rather forced by a pair of hydrostatic units to attempt to raise speed of the loaded axle; affording a neutral steering drive mode so that the crawler, when the tracks are stopped, will have freedom from any tendency to creep; and so utilizing the two hydrostatic units that they are in full time operation, overcontrolling the steering differential into forced differentialling for all hydrostatically fixed reduction drive ratios from faster axle to the slower one for turns, and overcontrolling the steering differential for a forced 1:1 fixed drive ratio between axles through automatic trim means to sense any differential speed error and immediately eliminate it.

Further features, objects, and advantages will either be specifically pointed out or become apparent when, for a better understanding of our invention, reference is made to the following description, taken in conjunction with the accompanying drawings which show a preferred embodiment thereof and in which:

Figure 1 is a schematic diagram in top plan of an arrangement of power source, a slip drive power train, and steering differential drive in a crawler tractor embodying the present invention;

Figure 2 is similar to Figure 1, but is simplified by parts omissions for illustrating how the differential control at one side only of the tractor is effected from the opposite side by strategic placement of a novel cross connection therein; and

Figure 3 is a circuit schematic illustrating the electrical control over the hydromechanical steering differential hereof.

More particularly, in Figure 1 of the drawings, a tractor 10 is shown having respective left and right endless crawler track assemblies 12 and 14 which are

powered for steering by driving, and a forward mounted diesel engine 16 with appropriate connections as a power source for the tracks. Specifically, prime power from the engine 16 is transmitted in a slip drive path through a hydrodynamic torque converter 17, a power shift transmission input shaft 19 and reversible, change speed transmission 22, a transmission propeller shaft 24, a rear axle differential 25 comprising a bevel gear 26 which is driven by a meshing pinion 27 on the propeller shaft 24, and an oppositely extending pair of controlled output axles 40 and 38 connected by the respective left and right final reduction gearing 32 and 34 to the corresponding track assemblies 12 and 14.

A spline 36 and a spline 35 on the respective output axles 40 and 38 are part of a path to be described and including dual left and right units 20 and 18 providing secondary control over the axles 40 and 38 and accomplishing steering by driving.

Hydraulically operated power brakes 37 and 39 provide tertiary control over the axles by set brake or drag brake action with respect to the fixed tractor steering housing 41 for frictionally independently arresting axle motion.

The secondary control over the axles 40 and 38 is provided by a variable ratio, dual unit, bidirectional drive 42 having crossfeed connections 44 and 46 for energy interchange between the units 20 and 18, and having pinion and gear speed reduction gearing 30 and 28 fast to the respective axle splines 36 and 35 so as to interconnect axles.

Because a reduced speed drive at fixed ratio can be afforded by the bidirectional drive 42 as from, for example, the pinion and gear reduction gearing 28 to the opposite pinion and gear reduction gearing 30, it will be apparent, in the steering drive arrangement if properly controlled, that so long as the drive means or differential 25 rotates under power it will drive the gearing 30 and

associated axle 40 at a fixed reduced speed ratio for steering the tractor in a turn about the reduced speed track side which is to the left as viewed in Figure 1.

Basic to the just alluded to, dual unit, bidirectional drive now to be explained, is the fact that the dual units, in order to provide the drive both ways, have the mutual capability inherently for each to be run as a motor when the power to be consumed is transferring from the other unit serving as generator, and to operate as the generator itself when delivery of the operating or motive power is to the other unit.

BIDIRECTIONAL DRIVE 42 -- FIGURE 1

Generally for purposes of drive 42, any conventional units can be employed wherein each of the two units is broadly a generator/motor. The crossfeed by energy interchange will in a larger sense be fluid current or electrical current between the two generator/motor units. And an interchange of the latter current at fixed shaft to shaft speed reduction ratios is accomplishable readily within the skill of the electrical arts in their present state of refinement. Selsyn generator/motors are suitable in such electrical applications, or other appropriate dynamos which are available on the market in stock or to order. So what more basically is involved is variable excitation or equivalent of the units to adjust the relative speed/output of each, whereby that unit with the relatively unchanged excitation or equivalent will operate slower so as to run the associated axle at fixed speed reduction ratio relative to the other unit and its axle.

It is found to be of a particular advantage herein that each generator/motor unit be a fluid-driving pump/fluid-driven motor unit. Therefore, it will be an incompressible medium which flows as the crossfed current. So the respective dual left and right units 20 and 18 are preferably positive displacement, hydraulic pump/motor units, with direct interdependence between their rotational

speeds and the transmitted quantity of the incompressible hydraulic fluid, such as oil.

Although a tilting head pump/motor unit will be equally effective for the unit 20 and for the unit 18, an axial piston swash plate type pump/motor is shown in each instance which is operable in two quadrant operation, i.e., as a motor and as a pump, and which because of the reversible transmission 22 is so operable in both of its directions of being rotated. Not only, therefore, is the capability of units 20 and 18 comparable with fixed displacement units each operable in both senses of rotation, either as a pump or as a motor, but also their delivery rate is adjustable because of the variable excitation availed from the positive displacement pump strokes which can be constantly changed in a single quadrant from zero to maximum by varying the setting angle of the swash plate of each in known manner.

A so-called right steering path is operated at its front end by a conventional right steering lever 57. The path includes a right mechanical linkage 52, a right electrical cross connection lead 172, and an actuable stroke setting mechanism 50 on the left unit 20 to vary the displacement thereof. The needed interfacing is provided by dual control circuitry 120 operating as transducer to electrically interconnect the mechanical linkage 52 to the electrical cross connection lead 172, and is provided by a left control valve assembly or actuator 56 operating as transducer to hydraulically interconnect the electrical cross connection lead 172 and the left, actuable stroke setting mechanism 50.

Pushing the handle of lever 57 forwardly so as to push the right steering linkage 52 to its extreme rearwardly, results in hydraulically setting the axial pistons of the left unit 20 at full stroke for its maximum positive pumping displacement.

A left steering linkage 54 is similarly operated at its front end by a left steering lever 64. The com-

ponents affected thereby, in order, are the dual control circuitry 120, a left electrical cross connection lead 174, a right control valve assembly 58, and a right actuable stroke setting mechanism 48 on the right hydrostatic unit 18 to vary the displacement thereof.

It is intentionally done in the explicit situation here to have the steering lever at each side of the vehicle connected to control the pump/motor unit at the diagonally opposite side, and so the electrical leads 172 and 174 are deliberately illustrated as criss-crossing diagonally in the vehicle.

The left and right units 20 and 18 are symmetrically identical, and have the same size, same speed capability, and same displacement. The units hydraulically intercommunicate their liquid in the manner of an outright exchange and by the connections 44 and 46. The pair are physically in an end to end relation, reacting primarily against one another axially rather than having their rotary thrust component directed outwardly so as individually to necessitate heavy outboard thrust bearings. For confining their outwardly acting coaxial static thrust component, the concentric units 20 and 18 are held by their casings between apertured heavy housing plates 68 and 70 and, as typified by the unit 18, its pump/motor shaft 72 is splined to the pinion 74 of the pinion and gear reduction gearing 28. The pinion 74 and shaft 72 are journalled in rollers of a bearing 76 carried by a tubular flange extension, not shown, welded to the adjacent heavy housing plate 70.

The units 20 and 18 in their end to end arrangement illustrated, are of the type as generally shown in companion Horsch U.S. Application Serial No. 75,788 filed September 17, 1979, which is owned by the same assignee and the disclosure of which is incorporated in entirety by reference.

In the description to follow of our secondary drive for making hydrostatic turns, a convenient means of differentiation to be kept in mind is that the variable

displacement pump/motor unit with the greater displacement goes slower, because for each revolution thereof, the companion unit with the lesser displacement must turn more than one revolution in order to positively displace commensurate liquid in their exchange. In the extreme the latter, when set for zero stroke, free wheels.

HYDROSTATIC TURNS BY SECONDARY DRIVE -- FIGURES 1, 2

Up to and at the point at which this secondary control function will be initiated, controls for the bidirectional drive 42 reside in a solid line home position as shown in Figure 1 wherein the units 20 and 18 rotate at the same speed and in the same direction and wherein their displacements are at maximum. Maximum displacement in the units is due to full stroke as set by the illustrated position of their steering levers 64 and 57. The levers are so positioned by return springs, in common use and not illustrated, which individually pull so as to bias the levers 64 and 57 with their handles full forwardly as illustrated.

In a left turn for example, as more readily followed in the stripped down illustration of Figure 2, initial hand pulling of the left steering lever handle 64 rearwardly toward the operator will cause slight pulling movement forwardly of the left linkage 54 consistent with its counter clockwise rotation in the direction indicated by an arrow. The stroke of the right pump/motor unit 18 will correspondingly decrease, and the resulting decreased displacement of right unit 18 will hydraulically force its opposite counterpart, the left unit 20, to relatively reduce its speed and the speed of the left axle 40 as controlled thereby during this secondary hydrostatic drive. The track assembly 12 to the left as viewed in Figure 2 slows relative to the right track assembly 14 so that the vehicle 10 inherently enters into the left turn called for.

Further pulling of the left steering handle 64 toward the operator causes the left turn to be more and

more severe, i.e., the radius of turn curvature shortens. Finally, hand pulling of the left lever handle 64 full rearwardly causes the right unit stroke control mechanism 48 to adjust the right unit 18 for zero displacement, hydraulically locking the left unit 20 for a so-called pivot turn about the stopped track 12 on the left as vieved in Figure 2. Release of the left lever handle 64 allows the return spring, not shown, to restore the displaced one 54 of the linkages so that the steering linkages at both sides occupy their home position.

The cross connection lead 174 serves an effective dual function. For a turn to the left, it enables the noted lever 64 to relatively speed up the right track 14 for the left turn.

Equally advantageously, for straight line steering the lead 174 establishes electrical communication with a fast axle speed sensor 220, hereinafter disclosed, to enable a fast axle signal from the latter to follow the path of the arrows through the straight tracking circuit 134, dual control circuitry 120, then through the lead 174 to cause speed up in similar way of the right axle 38; the latter axle can therefore be brought up automatically to the speed of the fast axle 40, whereafter the sensor 220 will cease having a signal that the axle 40 is turning any faster than the opposite axle 38. As viewed in proper perspective according to their barely perceptible magnitude in practice, these automatic speed corrections are simple speed trimming operations by the dual sensor, trim means we provide, and neither axle and its track can speed up appreciably before the sensors react and re-synchronize the two tracks.

An opposite turn can readily be visualized from Figure 2 for execution toward the right, executed by the operator for graduality or severity of turn up to a pivot turn as desired. Throughout the latter turn, about the stopped track 14, the opposite pump/motor unit 20 is set at zero stroke for accommodating infinite pump/motor speed of

rotation at zero displacement with no flow in or out, while the adjacent unit 18 at the right remains set for full stroke displacement in the pump/motor, thereby being hydraulically locked against rotation due to flow stagnation caused by the opposite unit 20. So all of the differential's drive at 25 is consumed in the output axle 40 with none consumed in the output axle 38 to which the hydraulically locked right unit 18 is drivingly connected. The sole portion of output absorbed by the free wheeling unit 20 will be the power thereto consumed as friction losses.

The preferred operation is that, at any given time, only one of the handles 64 and 57 (FIGURE 1) is disturbed out of its home position. At that time, one of the units 20 or 18 will be operating at full displacement for full hydraulic effectiveness. And yet, whichever unit is driving -- the full displacement unit or the other one -- will be transmitting only a share of the steering-by-driving power; the main driving power on the axles will be coming from the drive means or differential 25 so that the dual units 20 and 18 may therefore be smaller dimensioned and of much lower capacity than found in all-hydrostatic or all-electric dual path drive systems in which the units must be sized to transmit full traction power rather than just a share as required herein.

Should the operator pull to him the handles of the levers 64 and 57 both full rearwardly at the same time, each of the units 20 and 18 will in effect idle or free wheel with zero displacement, thus having no influence on the differential 25 no matter whether the terrain attempts to hold the tractor 10 in straight line movement or turning movement.

BRAKED TURNS BY TERTIARY DRIVE -- FIGURE 1

Our design allows us to use a standard tractor brake pedal assembly 96 to special advantage. The assembly includes a right pedal 97, a parking brake pedal 98, and a left brake pedal 100 as viewed in this figure.

The parking brake pedal 98, also serving as a service brake, is effective to depress not only the right brake pedal 97 but also the left brake pedal 100. A cross rod 102 carried by the parking brake pedal 98 is schematically shown to overlie the other pedals for their coordinate depression with pedal 98.

The right pedal 97 has a right valve connection 104 and the left pedal 100 has a left valve connection 106 by which the pedals, from selective foot pressure by the operator, independently apply or release pressure from and to the axle brake cylinders of the respective hydraulically operated power brakes 37 and 39. Depression of the left pedal 100 pivots the valve connection 106 in the direction of the arrow shown, to engage the left brake 37.

In an emergency resulting from failure of the bi-directional drive 42 hydrostatically or else mechanically such as by defective reduction gearing 30 or 28, a mode of steering brake control can be inaugurated by selective operation of the left and right brake pedals 100 and 97. So at each side of the vehicle, the operator can manually maintain a set brake or drag brake operation, and thus trued up, straight line driving can be accomplished and steering turns up to and including pivot braking can be accomplished in the emergency.

<u>REVERSE SETTING OF TRANSMISSION 22 -- FIGURE 1</u>

The steering remains consistent, being the same for rearward motion of a vehicle 10 as for forward motion and as determined by the setting of the transmission 22. Whenever the transmission is operating in reverse, either of the two things -- pulling the right lever 57 or, with hydraulic drive failure, depressing the right brake pedal 97 and pulling the right steering lever 57 -- immediately causes further slip of the converter 17 and slowdown of the right track 14 so as to execute a right turn rearwardly. Whenever the transmission 22 is operating in the forward settings, either of the same two things will cause

increased slip of the converter 17 and slowdown of the right track 14, so that the faster left track on the outside will produce a forward turn to the right.

One of the more commercially attractive features of our invention is that, through the addition of the hydrostatic pair of variable displacement pump/motor units and controls including appropriate linkage actuated steering connections, a commercial differential drive for tractors can easily be transformed in production from strict mechanical operation to bidirectional, infinitely variable, self-powered hydromechanical operation. And, only in the emergency already noted of hydrostatic drive failure, will the strict brake steering control be employed. By analogy to the latter dual brake system for brake steering, dual control circuitry is required for the hand lever system hereof, now to be dealt with in the broad sense.

DUAL CONTROL CIRCUITRY -- FIGURE 1

The dual control circuitry 120 has straight tracking control including a speed sensing unit or sensor 210 which senses the output speed of the right pump/motor unit 18 and right track 14. The speed sensing unit 210 includes a ferrous toothed gear 212 fixed at 35 on the right output axle 38. A pickup head 214 cooperates with the gear 212 to provide pulses at a rate which varies as a function of variations in the speed of rotation of the gear 212. The pickup head 214 is of a known construction and includes a coil disposed in a magnetic field which is affected by movement therepast of the teeth on gear 212.

Similarly, a second speed sensing unit 220 is provided in association with the left hydrostatic unit 20 and left track 12. The speed sensing unit 220 includes a ferrous toothed gear 222 fixed on the splines 36 of left output axle 40. Upon rotation of its teeth by the ferrous toothed gear 222, pulses are provided at a corresponding rate by a pickup head 224, which rate varies as a function of variations in the speed of rotation of the left hydrostatic unit 20 and left track 12.

The control further includes a straight tracking circuit 134 for comparing the output signals from the speed sensing units 210 and 220. Upon a variation in the output speed of one of the hydrostatic units 18 or 20 relative to the other unit, the comparitor circuit 134 can be adapted to provide an electrical straight tracking control signal to effect a reduction in the speed of the faster one of the hydrostatic units 18 and 20 and an increase in the speed of the slower unit. It is preferable, however, with the present configuration of variable displacement units 18 and 20 that the straight tracking control signal be a destroking signal so as to vary the displacement of only the slower running one of the units 18 and 20 by appropriate destroking for relatively speeding it up.

Various known dual control circuitry providing the straight line tracking which our invention requires can be found suitable, such as the electrical type as generally shown in the above noted U.S. Patent No. 3,914,938 which will now be explained and the disclosure of which is incorporated in entirety herein by reference.

ELECTRICAL CONTROL GENERALLY -- FIGURE 3

Briefly, one preferred embodiment of the electrical control as it appears in this figure is seen to include, in the dual circuitry 120, right and left drive control circuits 122 and 124 to effect operation of the actuators or control valve assemblies 56 and 58 to vary the displacement of the hydrostatic units 20 and 18.

Right and left steering circuits 128 and 130 are associated with the drive control circuits 122 and 124 for selectively destroking one or the other of the hydrostatic units 18 and 20 to make a turn. During straight line movement, tracking forwardly or rearwardly, the straight tracking circuit 134 is effective to eliminate differentialling at 25 by equalizing the net displacements of the hydrostatic units 18 and 20. That is to say, the identically sized and proportioned units 18 and 20 cannot in

practice be expected to be identically constructed or to wear identically, and so their gross displacements at full stroke will be at a slight variance requiring automatic trim control for equal net displacements and identical straight line speeds therebetween.

Central to the dual control circuitry 120 is a full stroke adjuster 140 for electrically pre-setting the hydrostatic units 18 and 20 with maximum swash plate angle for their rated maximum or full displacement. The adjuster 140 is a potentiometer having a wiper 142 which is moved relative to a resistance 144 upon actuation of a control lever, not shown. Such movement of the potentiometer wiper 142 relative to the resistance 144 varies the voltage from the adjuster 140 over a lead 154.

When the wiper 142 is in the grounded position illustrated in Figure 3, a zero adjustment voltage is provided and the hydrostatic units 18 and 20 are stroked out with a zero degree swash plate angularity. For inaugurating the steering effect of the units 18 and 20, the wiper 142 is moved upwardly as viewed in Figure 3 to provide a positive polarity voltage signal on the lead 154. Normally and preferably, the wiper 142 stays in an all-the-way-up position corresponding to full voltage and the full stroke condition of the units 18 and 20.

That full voltage available from the adjuster 140 is transmitted as a reference signal over the lead 154 and an interconnected lead 164 to an adder or summing amplifier 162 in the right drive control circuit 122, and is transmitted over the lead 154 and an interconnected lead 168 to a second adder or summing amplifier 166 in the left drive control circuit 124. The adders 162 and 166 also receive inputs from the steering circuits 128 and 130 and from the straight tracking circuit 134.

The adders 162 and 166 direct their respective electrical control signals over the right and left cross connection leads 172 and 174 which transmit them directly to the respective actuators or control valve assemblies 56

and 58. The signals effect operation of torque-motor-actuated control valves which hydraulically operate servos to port fluid under pressure and effect operation of the actuable pump/motor right stroke and left stroke adjusters 48 and 50.

STEERING CONTROL -- FIGURE 3

When the vehicle 10 in this figure is to be turned, the right steering circuit 128 is actuated to provide an electrical steering command signal to the summing amplifier 162. This steering command signal can be arranged to oppose the full stroke adjuster reference signal and be made effective to activate the actuator valve assembly 56 to cause the stroke adjuster 50 to destroke the left unit 20.

More particularly, the full stroke reference signal from the adjuster 140 is transmitted by lead 154 to an inverting amplifier 192 having a voltage gain of 1 and applying the negative voltage through a double branched conductor 194 in common to the right and left steering circuits 128 and 130.

Therefore, if the vehicle 10 is proceeding with straight line steering in either direction, the adjuster's electrical signal transmitted over the lead 164 to the summing amplifier 162 has the maximum-set, positive voltage referred to. Actuation of the right steering circuit 128 results in the transmission of a negative voltage steering command signal to the summing amplifier 162 over a lead 180 from a steering command signal generator 184. Hence, the summing amplifier 162 transmits a reduced voltage control signal, partially destroking the left hydrostatic unit 20 so as to change the hydraulically fixed drive ratio between units and turn the vehicle 10 to the right.

The right steering command signal generator 184 is a potentiometer having a resistance 186 and a wiper 188. When the wiper 188 is in the position as shown in Figure 3, it is connected directly with ground so that the steering

command signal generator 184 is ineffective to transmit a signal to the summing amplifier 162. Upon actuation of the steering command signal generator 184 by moving, as viewed in Figure 3, downwardly on the wiper 188 relative to the resistance 186, a steering command signal is transmitted over the lead 180 to the amplifier 162. This negative steering command signal modifies the positive reference voltage signal of the adjuster 144 over the cross connection lead 172 to reduce the voltage transmitted from the summing amplifier 162 to the actuator valve assembly 56. Upon such a relative reduction in voltage, the actuator valve assembly 56 proportionally destrokes the left hydrostatic unit 20 for the appropriate faster speed.

The foregoing voltage reduction occurred because of the negative voltage of double branched conductor 194 which is connected to the ungrounded end of the resistance 186. Thus, when the wiper 188 is downwardly moved along the resistance 186, the voltage transmitted over the lead 180 to the summing amplifier 162 is of opposite polarity to the voltage of the reference signal conducted over the lead 164. Pulling backwardly on the handle of the right steering lever 57 moves the wiper 188 downwardly as viewed in Figure 3 to a final point at which the negative voltage is exactly equal to and of opposite polarity to the positive reference voltage in lead 164, producing zero displacement in unit 20.

The left steering circuit 130 is of generally the same construction as the right steering circuit 128 and includes a steering command signal generator 196 which is connected to the summing amplifier 166. The left steering command signal generator 196 is a potentiometer having a resistance 198 which is energized at full negative voltage from the double branched conductor 194. Therefore, as viewed in Figure 3, upon upward movement of a slider or wiper 200 to a fully displaced topmost position, the voltage of the steering command signal conducted to the summing amplifier 166 is of equal absolute value, but of opposite

polarity, to the positive reference voltage from the adjuster 140 being conducted to the summing amplifier 166 over the lead 168; so for drastic left turn purposes, the affected unit 18 is caused to take an infinite speed, zero displacement setting hydraulically locking the companion hydrostatic unit 20 for a pivot turn of the vehicle 10 about the stationary track 12.

STRAIGHT TRACKING CONTROLS -- FIGURE 3

When the vehicle 10 is moving along a straight path in either the forward or reverse direction, the straight tracking control circuit 134 shown in this figure is effective to prevent those variations, which occur in the hydraulic drive ratio between the hydrostatic units 18 and 20, from allowing differentialling at 25 and consequent steering drift. To that end, a comparitor 228 compares the speed signals from the right and left speed sensing units 210 and 220. It stays satisfied when there is no speed error and provides a steady output; but the comparator 228 provides a digital signal to a digital-to-analog converter 230 when the output speed signal of one sensor 210 or 220 is higher or faster than the output speed signal of the other sensor. The comparitor 228 includes a bidirectional counter 234. During movement of the vehicle 10, the speed signal from the right sensor 210 is transmitted to the up terminal of the counter 234 and the speed signal from the left sensor 220 is transmitted to the down terminal of the counter 234.

When the drive differential 25 is turning free from differentialling, the pulse rates of the speed signals applied to the up and down terminals of the bidirectional counter 234 are equal. Therefore, the counter 234 has the referred to steady output to the digital-to-analog converter 230. But during unwanted differentialling when the higher speed output is at the right side, for example, of the differential 25, the relatively higher pulse rate of the speed signal from the sensor 210 pulses the counter 234

upwardly so that the increasing output of the digital-to-analog converter 230 goes more positive. This output is transmitted to an inverting amplifier 244 having a gain of 1. The resulting more negative output from the inverting amplifier 244 opposes the positive reference voltage already being transmitted to the summing amplifier 162 by the adjuster 140. Therefore, output voltage from the summing amplifier 162 is decreased to effect operation of the actuator valve assembly 56 to decrease the hydraulic speed ratio by partially destroking the opposite or left hydrostatic unit 20 so that it speeds up relatively.

At the same time, there is an additional effect which is available, although not necessarily utilized. The same output signal from the digital-to-analog converter 230 is transmitted through a non-inverting amplifier 248 having a gain of 1 to the summing amplifier 166. An effect therefore possible is that the resultingly more positive signal from non-inverting amplifier 248 will simply increase the positive reference voltage from the adjuster 140 over lead 168 to the summing amplifier 166. So under the right circumstance, the cross connection lead 174 could additionally actuate the actuator valve assembly 58 on the opposite side to increase the displacement of, and slow down, the already fully displaced right hydrostatic unit 18; that circumstance could obtain if, at the time, the normally full stroke adjuster 140 had only a partial stroke setting.

But the foregoing effect is not utilized generally as the rule and actually can be viewed as superfluous for two connecting reasons. In the first place, one or both of the hydrostatic units 18 and 20 operate at full stroke and they ordinarily work to their full ability and capacity as necessitated by their small size. In the second place, adding on more speed to the slower unit, e.g., 20, during differentialling, inherently proportionally takes away speed from the faster companion hydrostatic unit (18) because of the positive mechanical interconnection afforded between units 18 and 20 by the interconnecting gearing of

the intervening differential 25. Incidentally herein, the fixed ratio drive between units 18 and 20 through their hydraulic interconnection would be utterly without significance if the units did not have their present differential-gear interrelationship through their positive interconnection at 25, because without the latter there is no continuing drive ensuring that at least one unit 18 or 20 is continually forced to rotate and be capable of pumping.

If the vehicle 10 should be moving rearwardly, for example, and encounters a condition in which the load on the right track and hydrostatic unit 18 increases so that their output speed decreases relative to the more lightly loaded left hydrostatic unit 20, the speed signal from the left speed sensing unit 220 connected to the down terminal will drive the counter 234 downward so that the digital-to-analog converter 230 decreases output. The output is transmitted as a decreasing signal by the non-inverting amplifier 248 to the summing amplifier 166 where it opposes the positive reference voltage signal from the conductor 168, so as to decrease the voltage transmitted through the cross connection lead 174 to the actuator valve assembly 58. The assembly 58 therefore actuates the slower unit 18 with partial destroking action to increase it in speed to the speed of the faster, left hydrostatic unit 20. Again, the effect is an increase to the positive reference voltage on amplifier 162 so as to attempt an increased displacement setting on the faster unit 18, but the effect is not essential and is not utilized.

Or, by way of contrast, for the slight variant where the left track 12 drops on the downside of a bump to cause differentialling with the left unit 20 momentarily taking the greater forward output speed, the decreasing output from the digital-to-analog converter 230 is effective to increase output speed of the slower right hydrostatic unit 18. In other words, that converter output is transmitted as a decreasing signal by the non-inverting

amplifier 248 to the summing amplifier 166 where it opposes the applied reference voltage so as to decrease the voltage transmitted to the actuator valve assembly 58. Consequently, the swash plate of the unit 18 loses angularity, the unit 18 is partially destroked to increase its speed, and the slower unit 18 is therefore brought up to the speed of the faster left hydrostatic unit 20. Straight line 1:1 steering is immediately restored.

During turning of the vehicle 10 it is necessary to disable the straight tracking circuit 134. Thus, activation of either the right or the left steering circuits 128 or 130 results in the transmission of a signal to a disabling circuit 252. Upon receiving a signal from one of the steering command signal generators 184 and 196, the disabling circuitry 252 transmits a signal over a lead 254 to a hold terminal of the counter 234, thus holding the counter in a fixed, steady state output condition until the turn is completed. Upon turn completion, there can be no further signal from the disabling circuit 252. So the counter 234 is restored to operation, whereupon the cycle is repeated.

When the operator releases the handles of both steering levers 57 and 64, Figure 1, so that they rotate counter to the direction of the arrows shown, the steering levers take their home position which is considered the normal position and is shown in full lines. The normal operating condition of the vehicle 10 therefore is for automatic straight line steering which is maintained in either direction of movement selected because the axles are speed sensor synchronized. All other conditions are selectively set by the hand of the operator by displacing the handle of either steering lever rearwardly for putting the vehicle 10 in a turn.

Either way, automatic steering or steering by hand, a noteworthy controlled slip differential effect is an inherency hereof. Specifically, one of the dual hydrostatic units through the other is effective to control

uncontrolled slip of either relatively unloaded output by forcing the latter, for every turn per minute it attempts to start overrunning by its own speed increases, to increase the speed of the loaded output by a proportionate number of turns per minute; runaway is thus self-defeating. That is, if the vehicle turns right with the inside or near track 14 first encountering slick ice, that track while having no road load on it cannot begin uncontrolled slip. The reason is that the otherwise faster turning unit 20 will immediately start the transfer from loaded outside track 12 of a portion of the load thru unit 18 so as to load and slow down the track 14 before it can transform into a runaway track dissipating into air all of differential 25's output.

For what is believed the first time, a runaway axle with its track running on what can be treated theoretically as friction-free ice is manageable thru our infinitely adjustable, hydraulically fixed control to be brought down in speed to any incremental point between a 1:0 and a 1:1 speed ratio compared to the differential's loaded axle. Also as compared to the limited slip differential of the prior art and for what is believed the first time (the prior art differential runs inself out at 1:1 axle ratio if in fact able to achieve full friction, absolutely no slip lockup), our infinitely adjustable, hydrostatic control can further bring down the runaway axle's speed to any incremental point between a fixed 1:1 speed ratio and a fixed 0:1 speed ratio compared to the differential's loaded axle; in other words, our hydraulically fixed ratio system is just getting started when it slows down the slipping axle to the unslipping axle's speed, and can progressively continue the slowdown to where it hydraulically locks the slipping axle to a stop.

If the two hydraulic actuators 56 and 58 in Figure 1 are considered electrical excitation controls for two respective motor/generator units 20 and 18 in lieu of the pump/motor units described, then an all electric control

system can be employed for an electromechanical steering differential operation. That is to say, instead of the steering linkages controlling swash plates in the latter units, they will simply operate electrical controls such as suitable potentiometers and rheostats or the equivalent to fix the steering turn ratio between axles 40 and 38 through operation of the pair of crossfeed connected (44, 46) motor/generator units connected one to each axle. Here again, the cross linkage system is preferable whereby each steering lever controls electrical excitation of the generator/motor unit at the diagonally opposite side of the vehicle; but because of electrical distinctions and considerations encountered with some units suitable to provide electrical bidirectional drive, their control from an oppositely disposed steering lever is not essential and they can be controlled from a same-side lever without necessity for the cross connection system. Incremental adjustability of the levers 64 and 57 affords infinitely variable steering ratios from 0:1 to 1:1, hence, stepless steering.

In any case, push exerted from a towed load exerted at the rear of the present hydromechanically or electromechanically differentially steered vehicle will be fully utilized and in a way rendering it self-defeating and altogether ineffective to reduce the turn radius of curvature. In other words, that excess of torque incurred by the towed load's push toward the outside track tending to make the turn more severe is simply applied by the latter to the outside unit for regeneration of power, and is thereupon introduced into and from the unit inside as multiplied torque to the track taking the inside of that turn, thereby reestablishing balance at the sides.

What is claimed is:

1. Controlled slip differential with the opposite outputs having a bidirectional, variably adjustment set generator/motor unit, dual drive means connected thereto and interconnecting the outputs (12, 14) so that one (20) of the dual units through the other (18) is effective to control uncontrolled slip of either relatively unloaded output (14) by transferring thereto through said other unit (18) that portion of load from the relatively loaded output (12) which is determined by the variable setting of the one unit (20).

2. For use in vehicular steering-by-driving, a shaft driven differential system which when so driven is self-powered for effecting turns and self-powered for necessary differentialling corrections to effect straight line steering,

said system comprising:

an opposed pair of vehicle axles (40, 38) extending toward opposite sides of the vehicle;

an opposed pair of variably displacement set hydrostatic pump/motor units (20, 18) connected one in association with each of the vehicle axles so as to hydraulically lock the associated axle or to turn simultaneously therewith in mutual drive transmitting relation;

an interposed, shaft-driven differential (25) interconnecting the axles, mechanically operative when there is no speed differential error to positively turn both axles unidirectionally at the same speed ratio and mechanically operative under all differentialling conditions to turn at least one axle under power;

means (64, 57) to vary the displacement of either of the opposed units to points of infinite adjustability below the full displacement of the other down to zero displacement for hydraulically locking the latter unit; and

crossfeed interconnections (44, 46) between the opposed units insuring hydraulically fixed speed ratios

between 0:1 to 1:1 and 1:1 to 1:0 immediately either axle turns under power whereby the unit with the larger displacement forces the associated slower axle to turn and the unit with the smaller displacement forces the associated fast axle to turn in accordance with the variable displacement and hydraulically fixed speed ratio as set for differentialling.

3. In a differentially steered vehicle having its differentially driven outputs oppositely disposed, a bi-directional drive comprising variably adjustment set, generator/motor units with crossfeed interconnections common thereto to allow each unit by unassisted energy interchange strictly therebetween to cause the other to operate at speed reduction ratios relative thereto fixed according to the variable settings, and drivingly connected to different ones of the differentially driven outputs, and a steering drive differential with the outputs at its respective sides and interconnecting same in a power path in parallel therebetween with said units,

steering differential controls comprising the improvement of:

operator-selectible means (64, 57) operative to vary the setting of the unit at either side of the vehicle for relative speed up so that as a generator/motor it will establish a fixed speed reduction ratio downwardly therefrom directly to the unit at the other side acting as a speed reduction motor/generator to force the steering differential to turn the vehicle toward that other side; and

means (120, 134) operable in response to unwanted differentialling in the steering differential to automatically vary the setting of that certain unit on the lower speed side of the differential for relative speed-up so that as a speed reduction generator/motor it will establish a decreasing speed ratio thereto directly from the other unit acting as a motor/generator until the automatic

elimination of all differentialling forces the differential into straight line 1:1 steering of the vehicle.

4. In a vehicle equipped for full time hydromechanical steering by driving:

a drive differential (25) providing at the opposite sides thereof the traction drive outputs (40, 38) for the vehicle;

a hydrostatic bidirectional drive (42) connected in parallel with the differential comprising variably displacement set, hydraulically interconnected (44, 46) pump/motor units (20, 18) disposed each on a different side of the differential and with the output at that side connected thereto for drive at speed increasing ratios fixed according to that unit's displacement setting;

an oppositely disposed pair of steering circuit means (128, 130) for steering to the right and left sides, respectively, operable to vary the displacement of the unit concerned with infinite adjustability throughout the full range of a 1:1 to 0:1 speed reduction ratio of that unit and the one of the said differential outputs connected thereto at that side, for the secondary steering turn driving of the venicle by said outputs; and for their primarily mechanical straight line driving thereof,

trim adjustment means (234, 230) for measuring unwanted differentialling as an output speed signal error to the desired 1:1 ratio through the drive differential and for automatically incrementally reducing the displacement of the slower running unit to speed it up until the unwanted unit-differentialling is eliminated.

5. In a vehicle equipped for full time electromechanical steering by driving:

a drive differential (25) providing at the opposite sides thereof the traction drive outputs (12, 14) for the vehicle;

an electrical bidirectional drive (42) connected in parallel with the differential comprising variably excitation set, electrically interconnected, generator/ motor units (20, 18) disposed each on a different side of the differential and with the output at that side connected thereto for drive at speed increasing ratios fixed according to the comparitive excitation settings;

an oppositely disposed pair of electrical steering circuit means (128, 130) for steering to the right and left sides, respectively, operable to vary the comparitive excitation setting with infinite adjustability throughout the full range of a 1:1 to 0:1 speed reduction ratio of either unit and the one of the said differential outputs connected thereto at that side, for the secondary steering turn driving of the vehicle by said outputs; and, for their primarily mechanical straight line driving thereof,

trim adjustment means (230, 234) for measuring unwanted differentialling as an electrical output speed signal error from the desired 1:1 ratio through the drive differential and for automatically incrementally causing relative speed up in the slower running unit by comparitive excitation adjustment until the unwanted unit-differentialling is eliminated.

6. A vehicle equipped for full time hydromechanical steering by driving comprising:

a pair of oppositely extending axles (38, 40) disposed one at each side thereof;

first and second, likewise disposed, variably displacement set, hydrostatic pump/motor units (18, 20) adapted therebetween with hydraulic interconnections (44, 46) cross feeding to interchange their hydraulic fluid in general under unequal displacement and consequent differential in speed, and with the larger displacement unit always running slower except when undesired for some condition such as straight line, 1:1 axle ratio, steering requires, and each unit drivingly connected to the axle disposed at that side;

a drive differential (25) connected mechanically in parallel with the first and second hydraulically interconnected units and interconnecting the axles;

first actuator means (58) operable for varying the displacement of the first unit (18) under a reducing displacement for speed increases thereof, and vice versa;

second actuator means (56) operable for varying the displacement of the second unit (20) under a reducing displacement for speed increases thereof, and vice versa; operation of said first acuator means (58) to vary the displacement of said first untit (18),

second electrical control means (128) for effecting operation of said second actuator means (56) to vary the displacement of said second unit; and

straight line steering means (234, 230) sensitive to any differential in speed obtaining when the units desirably are driving the axles in a fixed 1:1 speed ratio for effecting operation of one of said actuator means to automatically reduce the displacement of the slower running unit to speed it up until the undesired speed differential is eliminated.

7. In a differentially driven vehicle (10) with full time steering-unit steering and including a drive differential (25) with drive axles (40, 38) extending to the opposite sides of the vehicle:

pairs of axle-connected speed sensors (210, 220) and of axle-connected variably adjustment set, generator/motor units (20, 18), all disposed one at each side of the vehicle;

crossfeed interconnections (44, 46) affording common means for each unit to operate the other at speed ratios relative thereto fixed according to the variable settings; and

sensor-sensitive trim means (134) to automatically speed up the slower axle and unit by changing the variable setting of the latter until any speed error due to differentialling is eliminated.

8. In a differentially driven vehicle with full time steering-unit steering and including a drive differential (25) with drive axles (40, 38) extending to the opposite sides of the vehicle:

pairs of axle-connected speed sensors (210, 220), axle-connected variably adjustment set, generator/motor units (20, 18), and manual steering levers (64, 57) for the respective units, all disposed one at each side of the vehicle;

crossfeed interconnections (44, 46) common to the units to allow each by unassisted energy interchange strictly therebetween to cause the other to operate at speed ratios relative thereto fixed according to the variable settings; and

sensor-sensitive trim means (134) connected to vary the units' settings, operative in response to a temporary speed error sensed between the sensors due to differentialling, to automatically speed up the slower axle and unit by changing the variable setting of the latter until all speed error due to differentialling is eliminated.

9. The invention of Claim 8, characterized by:

each steering lever (64, 57) at the side of the vehicle operatively connected to the generator/motor unit (20, 18) at the opposite side, and the sensor-sensitive trim means (134) operatively connecting each speed sensor at the side of the vehicle to the variable setting of the generator/motor unit at the opposite side, all to speed up the latter through change of its variable setting.

10. A vehicle steered by driving having:

pairs of steering levers (64, 57), traction drive outputs (40, 38), and variably displacement set, hydrostatic pump/motor units (20, 18) controlled by different ones of the pair of levers, all disposed one at each side of the vehicle, the units adapted therebetween with crossfeed connections (44, 46) to interchange their fluid and

each drivingly connected to the one of the outputs at that side, for their lever-controlled, secondary steering turn drive; and, for their straight line 1:1 primarily mechanical drive,

a drive differential (25) interconnecting the outputs, and disablable trim means (134) for measuring unwanted differentialling as an output speed signal error from a desired 1:1 ratio through the drive differential and for automatically incrementally reducing the displacement of the slower running unit until the unwanted differentialling is eliminated;

each steering lever (64, 57) at the side of the vehicle operatively connected (188, 252, 254, 200) in common to the pump/motor unit at the opposite side and to the disablable trim means so that, coordinately with predetermined initial and further steering movement, such lever immediately disables the automatic trim means and progressively decreasingly varies its pump/motor unit displacement so that as a motor/pump it will progressively reduce speed of the other unit acting as a speed reduction pump/motor.

11. In a differentially driven vehicle with full time generator/motor-steering-unit steering and including a differential drive with opposed drive axles:

bidirectional drive means with opposed interconnected generator/motor units each connected to a different one of the axles;

trim means (134) with opposed speed sensors (210, 220) each connected to a different one of the axles effective for causing the units automatically to synchronize same; and

means (57, 64) to override the trim means effective for causing the units to initiate differentialling in the differential drive.

12. In a tracked vehicle with the tracks at the sides, a bidirectional drive therefor comprising variably

adjustment set, generator/motor units with crossfeed interconnections thereto and actuable to be set to allow each unit, by unassisted energy interchange strictly therebetween, to cause the other to operate at speed reduction ratios relative thereto fixed according to the variable settings, and drivingly connected each one to a different one of the tracks, and a steering drive differential interconnecting the tracks in a power path in parallel therebetween with said units,

the improvement comprising:

pairs of respective actuators (56, 58) for the actuable settings of the corresponding associated units, and of sensors (210, 220) for the tracks' speeds, and of levers (57, 64) whereby the steering differential is caused to steer the vehicle by a differential in track speeds, all disposed one at each side of the vehicle;

cross connections (172, 174) between the levers and actuators enabling the track at each side to be relatively slowed because the cross connection affords to the lever at that side control over the opposite side actuator to vary the setting with increases in the speed reduction ratio of its associated variably set unit in the bidirectional drive; and

cross connections (Figure 2) between the sensors and actuators enabling the track at either side exhibiting a dominant differential in speed to be relatively slowed because the cross connection affords to the sensor at that side control over the opposite side actuator to vary the setting with desired decreases in the speed reduction ratio of its associated variably set unit in the bidirectional drive until the speed differential between tracks is eliminated.

13. In the mode of differentially steering a vehicle (10) having its differentially driven outputs oppositely disposed, a bidirectional drive comprising variably adjustment set, generator/motor units (20, 18) with cross-

feed interconnections common thereto to allow each unit by unassisted energy interchange strictly therebetween to cause the other to operate at speed reduction ratios relative thereto fixed according to the variable settings, and each one drivingly connected to a different one of the differentially driven outputs, and a steering drive differential (25) with the outputs at its respective sides and interconnecting same in a power path in parallel therebetween with said units,

the improved steps of:

selectively turning a tracking vehicle by manually varying the setting of the unit at either side of the vehicle for relative speed-up so that as a generator/motor it will establish a fixed speed reduction ratio downwardly therefrom directly to the unit at the other side acting as a speed reduction motor/generator to force the steering differential to turn the vehicle toward that other side; and

straight tracking a turning vehicle automatically in response to unwanted differentialling in the steering differential by automatically varying the setting of that certain unit on the lower speed side of the differential for relative speed-up so that as a speed reduction generator/motor it will establish a decreasing speed ratio thereto directly from the other unit acting as a motor/generator until elimination of all differentialling forces the differential into 1:1 straight tracking steering of the vehicle.

14. In the mode of steering a vehicle by driving, said vehicle having pairs of companion selectible steering-signal-originating levers (64, 57), generator/motor units (20, 18), oppositely extending axles associated therewith, and axle speed-error-signal-originating sensors (210, 220), all disposed one at each side of the vehicle, said units together having crossfeed interconnections in common effective in vehicle turns to allow each unit by unassisted

energy interchange strictly therebetween to cause the other to operate at speed reduction ratios relative thereto, and each having actuator means (56, 58) to render each a variable setting unit for setting the relative speed reduction ratio at which such unit will operate the slower other unit, said sensors (210, 220) providing a dominant speed error signal from the sensor at the side of the vehicle with the faster axle, and an interposed differential (25) common to the axles for mechanically driving same in a power path in parallel therebetween with said units, the improved steps for turn steering and straight line steering of the vehicle comprising:

applying the selected steering signal originating at one side of the vehicle to the signal responsive actuator of the variable setting unit at the opposite side of the vehicle so that the latter will operate the unit at said one side at a speed reduction ratio for turning the vehicle toward that one side; and

applying the dominant speed error signal originating at one side of the vehicle to the signal responsive actuator of the variable setting unit at the opposite side of the vehicle so that the latter will be automatically operated at a relative speed increasing ratio by the unit at said one side until the speed error is eliminated.

15. In differentially steering a vehicle having its differentially driven outputs oppositely disposed, a bi-directional drive (42) comprising variably displacement set, generator/motor units (20, 18) with crossfeed interconnections common thereto to allow each unit by unassisted energy interchange strictly therebetween to cause the other to operate at speed reduction ratios relative thereto fixed according to the variable settings, and drivingly connected to different ones of the differentially driven outputs, and a steering drive differential (25) with the outputs at its respective sides and interconnecting same in a power path in parallel therebetween with said units,

the improved alternative steering modes comprising:

manually varying the setting of the unit at either side of the vehicle for relative speed-up so that as a generator/motor it will by energy interchange establish a fixed speed reduction ratio downwardly therefrom directly to the unit at the other side acting as a speed reduction motor/generator to force the steering differential to turn the vehicle toward that other side; and

automatically in response to unwanted differentialling (Figure 2) varying the setting of that certain unit (18) on the slow side of the differential for relative speed-up so that as a speed reduction generator/motor (18) it will establish a decreasing speed ratio thereto directly from the other unit (20) acting as a motor/generator until elimination of all differentialling forces the differential into straight line 1:1 steering of the vehicle.

16. Regenerative method to retain a fixed curvature of vehicle turn while steering by driving tracks thereon with an hydromechanical steering differential, such vehicle subject at times to a towed load push, said differential having variable stroke setting, cross feeding, generator/motor units one disposed with and connected to the track taking the outside on a turn and one with and connected to the track taking the inside of that turn, effective with the outside unit at reduced stroke to multiply the torque supplied to the unit inside at an inverse ratio to the magnitude of the outside unit's stroke setting, any such push tending to make the turn more severe by rendering the outside track subject to an excess of external driving torque, said method as incurred by the excess torque feeding into the track outside, comprising the steps of:

applying therefrom the excess torque to the unit outside for regeneration of the power;

transferring to the unit inside the regenerated torque in the torque multiplication ratio as established

inherent to the reduced stroke setting of the unit outside; and

introducing from the unit inside the torque, as multiplied, to the track taking the inside of the turn.

17. Regenerative hydromechanical steering differential system effective to retain a fixed curvature of vehicle turn while steering by driving the tracks thereof, such vehicle subject at times to a towed load push, the differential of said system having set displacement, cross feeding, generator/motor units one disposed with, and connected to, the differential driving output and driven track taking the outside on a turn and one disposed with, and connected to, the differential driving output and driven track taking the inside of that turn, any such push tending to make the turn more severe by rendering the outside track subject to an excess of external driving torque, said unit outside having means to reduce its displacement setting ensuring no diminution of torque as the excess outside torque is applied by the outside track to the unit outside for regeneration of the power, is transferred without diminution to the unit inside as regenerated power, and is utilized by introduction from the unit inside to the inside track.

FIG. 1

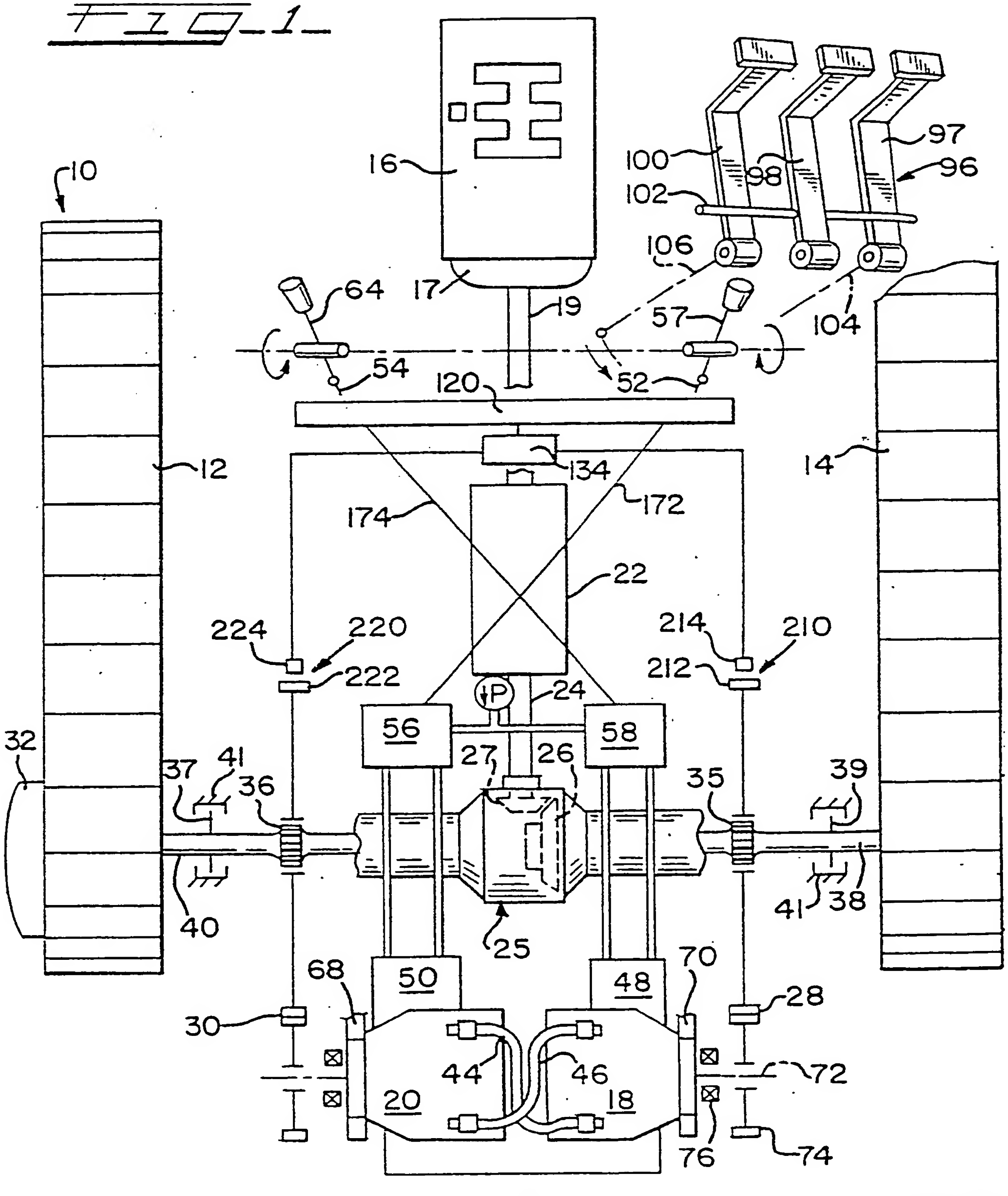
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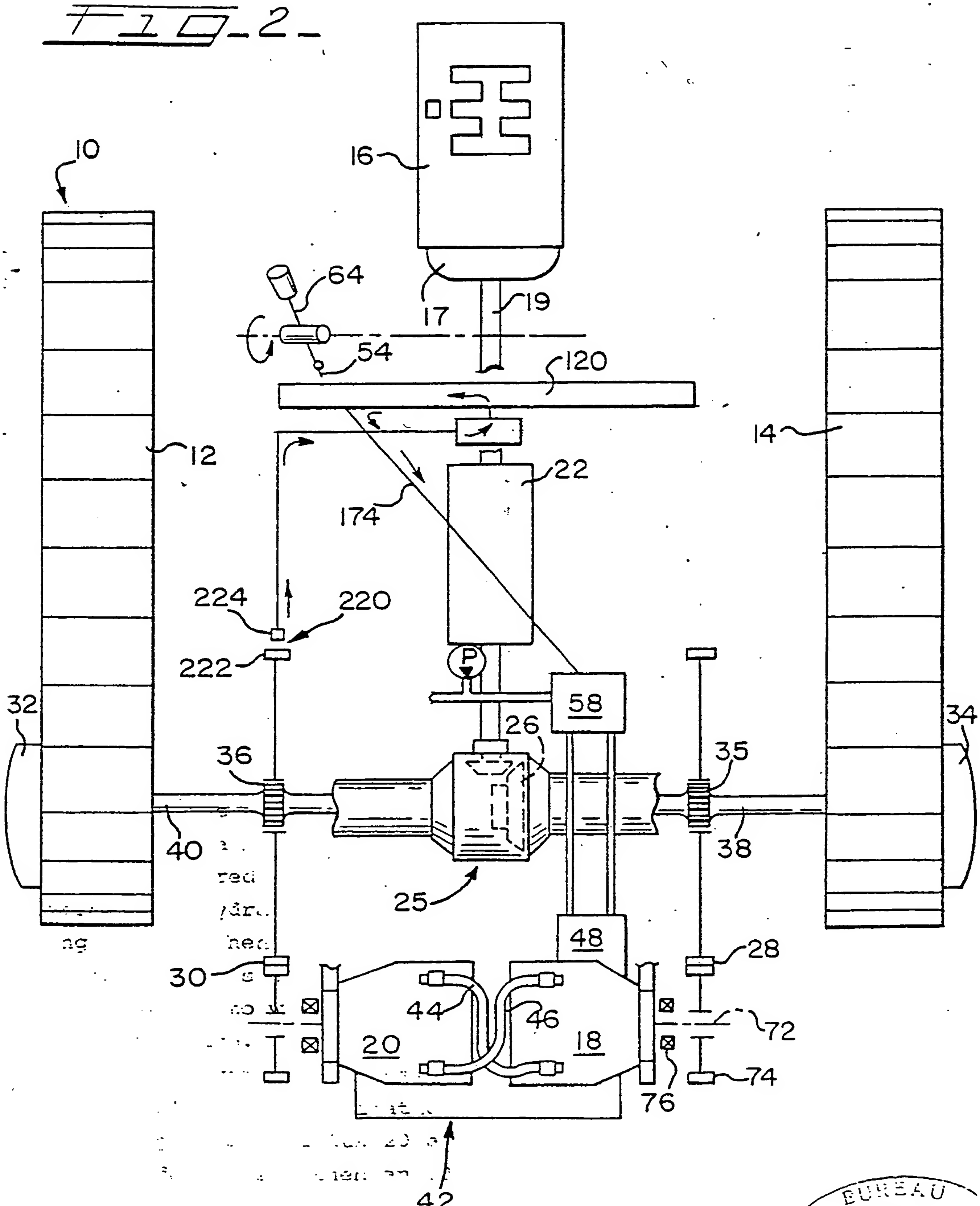
FIG. 2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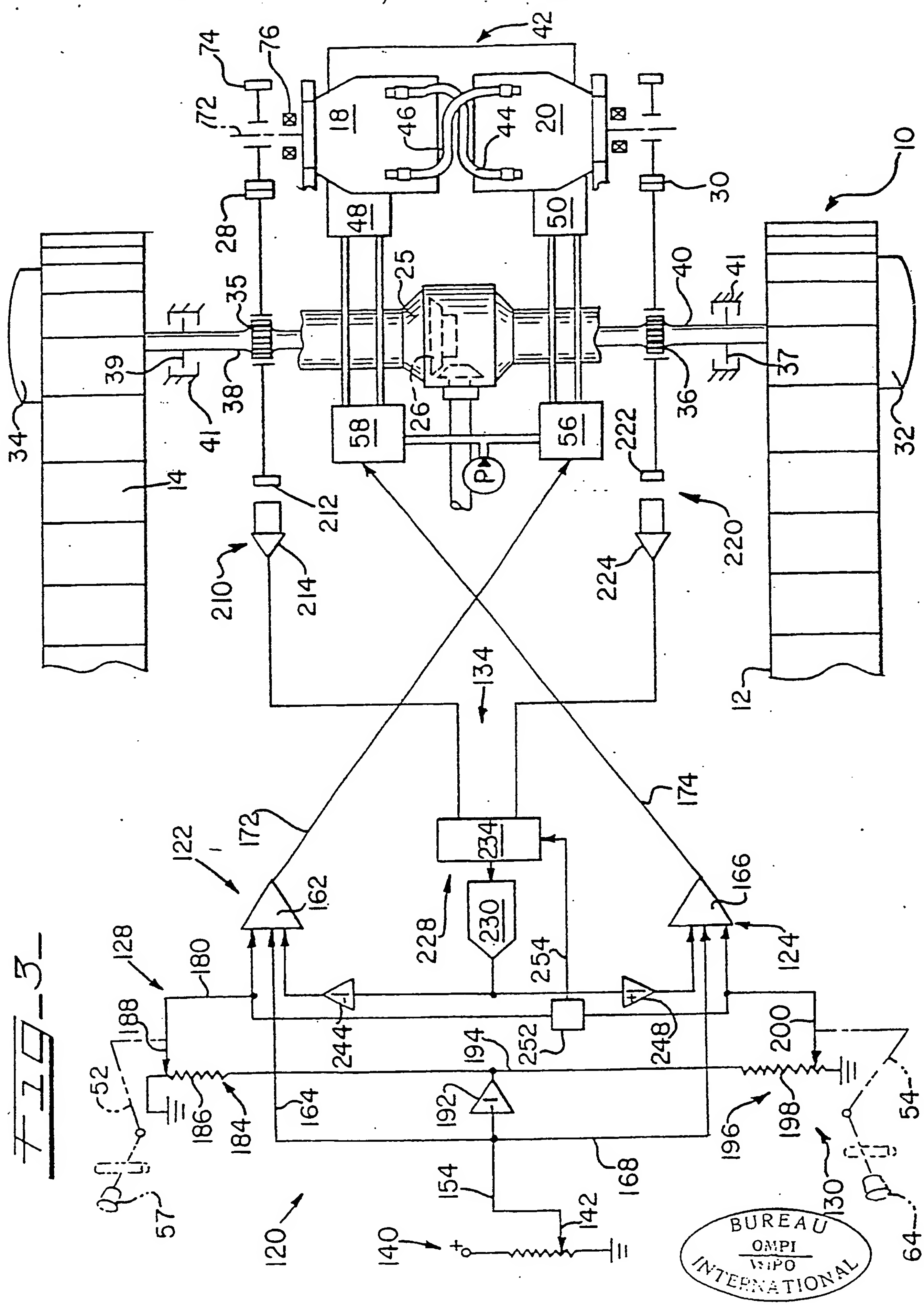
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FIG-3

INTERNATIONAL SEARCH REPORT

International Application No PCT/US80/00695

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

B62D 11/00; F16D 31/02; F16H 37/06; F16H 1/38 ; F16H 1/40

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	180/6.44, 6.2, 6.7 ; 60/420 74/665S, 665T, 686, 687, 710, 710.5, 711, 713, 732

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
X	US, A, 2,377,354 published 5 June 1945 Merritt	1,2
X	US, A, 3,371,734 published 5 March 1968, Zaunberger et al	1,2
E	US, A, 4,236,595 published 2 December 1980, Beck et al	3-17
X	US, A, 4,175,628 published 27 November 1979, Cornell et al	3-17
X	US, A, 3,862,668 published 28 January 1975, Ward	3-17
X	US, A, 4,019,596 published 26 April 1977, Crull	3-17
X	US, A, 3,914,938 published 28 October 1975, Cornell et al	3-17
A	US, A, 2,336,911 published 14 December 1943, Zimmermann	1-17
A	US, A, 3,938,604 published 17 February 1976, Kugler et al	1-17
A	US, A, 4,174,762, published 20 November 1979, Hopkins et al	1-17
A,T	US, A, 4,246,992, published 27 January 1981, Hakes et al	1-17

* Special categories of cited documents: [15]

"A" document defining the general state of the art

"E" earlier document but published on or after the international filing date

"L" document cited for special reason other than those referred to in the other categories

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but on or after the priority date claimed

"T" later document published on or after the international filing date or priority date and not in conflict with the application, but cited to understand the principle or theory underlying the invention

"X" document of particular relevance

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
27 March 1981	03 APR 1981
International Searching Authority [1]	**Signature of Authorized Officer [10]**
ISA/US	[signature]

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, 16 with indication, where appropriate, of the relevant passages 17	Relevant to Claim No
A	US, A, 2,401,628 published 4 June 1946, Eksergian	1-17
A	US, A, 2,446,242 published 3 August 1948, Orshansky, Jr.	1-17
A	US, A, 2,580,946 published 1 January 1952, Orshansky, Jr., et al	1-17
A	US, A, 1,984,830, published 18, December 1934, Higley	1-17
A	US, A, 2,874,591, published 24 February 1959, Thoma	1-17
A	US, A, 3,169,595, published 16 February 1965, Shepherd	1-17
A	US, A, 3,383,952, published 21 May 1968, Christenson	1-17
A	US, A, 3,461,744, published 19 August 1969, Booth	1-17
A	US, A, 2, 996,135 published 15 August 1961, Grabow	1-17
A	US, A, 2,394,119 published 5 February 1946, Tomik	1-17
A	US, A, 3,744,584, published 10 July 1973, Swift	1-17
A	US, A, 3,815,698, published 11 June 1974, Reed	1-17
A	US, A, 4,093,048 published 6 June 1978, Hakes et al	1-17
A	US, A, 2,336,912 published 14 December 1943, Zimmermann	1-17
A	US, A, 2,353,554 published 11 July 1944, Gates	1-17